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US Army Corps
of Engineers

EVALUATION OF THE COASTAL FEATURES MAPPING SYSTEM FOR SHORELINE MAPPING

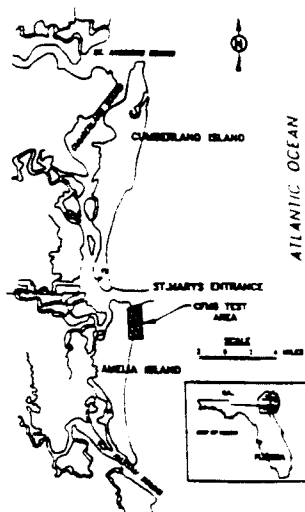
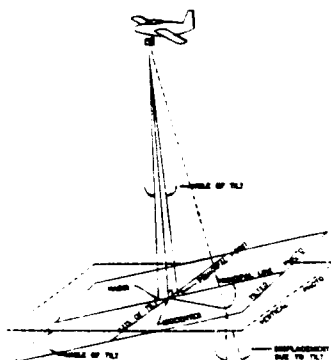
by

Steven G. Underwood, Fred J. Anders

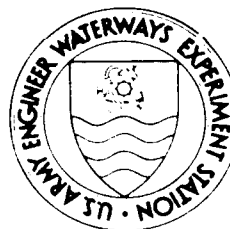
Coastal Engineering Research Center

DEPARTMENT OF THE ARMY

Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



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13. ABSTRACT (Maximum 200 words) <p>Since many coastal areas are subject to frequent change due to environmental conditions or commercial development, it is often difficult to fulfill the optimum requirements for ground control when mapping from aerial photographs. For this reason, a series of tests were devised to evaluate the accuracy of the Coastal Feature Mapping System (CFMS) for typical shoreline mapping applications encountered by the US Army Corps of Engineers. Major variables tested included the number of ground control points (GCP's) employed in the solution and their distribution. Ground control points digitized from 1:24,000 scale US Geological Survey topographic maps were used in various combinations to orient 1:9,600 scale aerial photographs for coordinate retrieval. It was found that the accuracy of X-, Y-coordinates determined from the photographs is governed by the distribution and accuracy of GCP's. Maximum accuracy is obtained when all measured points are within the area bounded by the GCP's. Although at least four GCP's are required</p> <p style="text-align: right;">(Continued)</p>				
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for the solution, additional points allow possible mistakes to be identified and corrected interactively. In all tests, the errors were consistent with those associated with 1:24,000 scale base map as defined by National Map Accuracy Standards. The user's guide contained adequate information about overall program operation, but lacked sufficient guidance for first time users.



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PREFACE

In 1986 the Coastal Structures and Evaluation Branch (CSEB) of the Engineering Development Division (EDD), Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), contracted with the University of Georgia Research Foundation, Inc., for the Center for Remote Sensing and Mapping Science to develop personal computer software to assist in shoreline mapping efforts. Specifically, the software was to facilitate use of air photographs in mapping coastal feature changes. The intent of the CSEB was to apply this software to current shoreline mapping problems and to future mapping efforts within CERC and Corps-wide. The software, called Coastal Features Mapping System (CFMS), was completed in 1989. This report presents an evaluation of CFMS for use in Corps shoreline mapping applications.

This report was prepared by Messrs. Steven G. Underwood and Fred J. Anders of the Coastal Geology Unit (CGU), CSEB, CERC. Funding for software development was provided through the Evaluation of Navigation and Shore Protection Structures Program, and funding for this report was provided by the Barrier Island Sedimentation Studies Work Unit 31665. This study was sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). Program manager is Dr. C. Linwood Vincent, and HQUSACE Technical Monitors are Messrs. John H. Lockhart, Jr.; John G. Housley; James E. Crews; and Robert H. Campbell.

The work was conducted under the general supervision of Ms. Joan Pope, Chief, CSEB; Mr. Thomas Richardson, Chief, EDD, CERC; Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and Dr. James R. Houston, Chief, CERC. Other CERC personnel participating in the report preparation included: Ms. Karen Pitchford, Atlantic Research Corporation, who provided technical assistance and helped with experimental design criteria for CFMS; Ms. Lynn Bessonette, CERC contract student, who contributed AutoCAD drawings for this report; Mr. Mark Hansen and Dr. Mark R. Byrnes, both formerly with CERC; Dr. Roy Welch and Mr. Tommy Jordan from the University of Georgia's Center for Remote Sensing and Mapping Science, who provided technical reviews; and Ms. Laurel Gorman, EDD, CERC, who assisted with the Kings Bay background.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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AN EVALUATION OF THE COASTAL FEATURES MAPPING SYSTEM

FOR

SHORELINE MAPPING

PART I: INTRODUCTION

Shoreline Change Mapping

1. Knowledge of past and present shoreline change rates is essential for most planning, geomorphic, and engineering projects in the coastal zone. Quantitative historical changes are used to develop sediment budgets, monitor engineering modifications to the shoreline, plan engineering projects, examine geomorphic variations in the coastal zone, examine the role of natural processes in modifying shorelines, establish set back lines, and predict future shoreline changes. This information can be obtained from either continuous field surveys or from current and historic maps and vertical aerial photographs. The latter does not require extensive field time nor expensive equipment to collect data and, therefore, it is often the most economical means of measuring shoreline change. Scientists, engineers, and planners have recognized the usefulness of mapping shoreline position to delimit areas of erosion and accretion. Historical maps dating back to the middle to late 1800's and near-vertical aerial photographs (referred to throughout the remainder of the text as air photos) beginning in the 1930's are available for most of the U.S. shoreline, providing a length of record which is not usually available with field surveys. Therefore, historical change in shoreline position based on maps and air photos is a useful tool to examine past coastal changes which have resulted from incident processes and to project future changes in shoreline response.

2. Technically, the shoreline is the line of intersection defined by land, sea, and air, and it is in a constant state of change, making mapping difficult. Shoreline position and configuration at any point in time and space is a function of five primary factors: pre-existing geology, sediment supply, process energy, sea level rise, and human intervention. Interaction among these factors determines shoreline location at any instant in time.

Developing accurate maps is a difficult task anywhere, but mapping the shoreline presents additional problems because of its constantly changing position. Historical analysis of shoreline changes is therefore hindered by the long periods of time between successive maps. Air photos can supplement maps by recording the shoreline at a given time and they can be collected as frequently as funding permits. They do, however, present several potential problems.

3. Although the difficulties in preparing a shoreline map are numerous, comparing shoreline changes on successive maps and air photos is even more challenging. Shoreline maps must be evaluated for accuracy, corrected to reflect a common tidal datum, and brought to a common scale before data from successive maps can be compared. Electronic digitizers and computers with a variety of software have greatly facilitated the use of maps for comparing shoreline position. However, initial map accuracy must still be evaluated to assess the significance of measured changes. Air photos must be evaluated for a variety of distortions inherent in the photographic process which must be rectified if they are to be treated as maps. Several techniques have been developed to correct distortions in air photos so that they may be used to supplement map data. These techniques, of which the Coastal Features Mapping System (CFMS) is one, will be discussed in this report. To date, none of the available techniques have successfully removed all photographic distortion at a reasonable cost.

4. The primary purpose of this report is to evaluate the use of CFMS for typical shoreline mapping applications encountered by the Corps of Engineers. These applications generally involve the use of both maps and air photos. CFMS allows the user to digitize information from both data sources and draw map overlays of corrected shorelines. The accuracy and ease with which this is accomplished are evaluated. In addition, a summary is provided of the various techniques developed to quantify historical shoreline change, typical problem areas and sources of error, and how CFMS contributes to shoreline change evaluation.

The Coastal Features Mapping System

5. The CFMS is a PC-based program that numerically removes photographic distortions common to air photos of the coastline. The general technique employed involves selection of ground control points (GCP's) for which exact position is known in a cartesian coordinate system. Location of these points could be determined from field surveys or from a base map. The points are identified on air photos, and their position is corrected with reference to the known location using a least squares fit. The correction applied to control points is then used to adjust shoreline points being mapped. The end result is a series of shoreline points that are adjusted to compensate for photographic distortion and a composite map of all shorelines (generated from original maps and air photos) at a common scale. This technique offers the advantages of ease of use and speed of operation and it is a fairly inexpensive correction technique. However, it does not completely remove all distortion and is particularly limited in areas of high relief.

6. One additional benefit of CFMS is its ability to extend control into areas where none exists. Typically, the exact coordinates of stable ground control points, upon which the correction factor is based, are difficult to locate. This is especially true in many unpopulated coastal areas. CFMS uses a bridging technique to extend control between aerial photos containing GCP's to up to 2 intermediate photos that have few stable points or none at all.

PART II: AN INTRODUCTION TO MEASURING SHORELINE CHANGE

7. A variety of techniques have been developed to extract shoreline change data from maps and air photos. These techniques range from purely mechanical measurement of shoreline position through automated systems. Cost generally increases with automation, but so does ease of data collection and accuracy with which shoreline change is known. A discussion of the various techniques used is prefaced by a discussion of typical problems associated with using maps and air photos for determining shoreline change. These problems have important bearing on data accuracy and therefore should be given careful consideration before starting an analysis.

Problem and Sources of Error

Recent Maps

8. The accuracy of shoreline change measurements depends on map scale. The smallest field distance measurable on a 1:20,000 scale map is 4 m (13 ft, Tanner 1978). Shoreline measurements can only be as accurate as the original maps themselves. Accuracy depends on the standards to which each original map was made and on changes which may have occurred to a map since its original publication. Since 1941 strict standards of accuracy have been defined for published maps. For examining shoreline position, the two most commonly available maps are US Geological Survey (USGS) Quadrangles and National Ocean Service (NOS) Charts. Both of these map types meet or exceed national map accuracy standards. United States National Map Accuracy Standards (Appendix 6, Ellis 1978) state:

"For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch [0.846 mm] measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch [0.508 mm]. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points

of small buildings); etc."

9. USGS topographic maps at a scale of 1:24,000 are the most commonly used maps for determining shoreline change. Applying the accuracy standard to these maps, maximum allowable error for 90% of the stable points is 12 m (40 ft). The accuracy with which any non-stable shoreline point is located could be less. NOS produces a variety of nautical charts at a variety of scales. For determining shoreline change the most commonly used chart is the Topographic (T) Sheet, which is the basic chart from which nautical and aeronautical charts are constructed. T sheets are generally produced at a scale of 1:10,000, although 1:5,000 and 1:20,000 charts have been made. At the 1:10,000 scale, national standards allow up to 8.5 m (28 ft) of error for a stable point. Other non-stable points are located with less accuracy, however, features critical to safe marine navigation are mapped to standards stricter than national standards (Ellis, 1978). The shoreline is mapped to within 0.5 mm (.02 inch, at map scale) of true position, which at 1:10,000 scale is about 4.9 m (16 ft) on the ground. Fixed aids to navigation and objects to be charted as landmarks must be located to within 3 m (10 ft) at this scale. In a shoreline mapping project using NOS charts, 36 random features such as road intersections and shoreline features, including points of marsh, were scaled from maps compiled from air photos. These features were located by field traverse and were compared with the geodetic coordinate values. The check revealed a maximum error of ± 3.0 m (10 ft, Everts, Battley, and Gibson 1983).

10. For accurate shoreline change measurement, NOS T sheets are the preferred data source. However, in cases where T sheets are not available or where a rapid and less accurate estimate of shoreline change is sufficient, such as areas where shoreline change is very large, USGS topographic maps can be used with confidence. Other maps depicting the shoreline may also be available in US Army Corps of Engineers offices and State and Local government offices. Usefulness of these maps for quantifying shoreline change depends on their accuracy standards and scale.

11. As previously mentioned, map accuracy also depends on what changes the map has undergone since production. Most important are changes in horizontal and vertical datums and physical changes resulting from shrinking

or stretching of the medium on which the map is printed. Horizontal and vertical datums were standardized in 1927 and 1929 respectively. Maps completed prior to this time require correction to the coordinate system to conform with new datums. In 1983, the horizontal datum (North American Datum - NAD) was readjusted using a newly defined ellipsoid referenced to the earth's center of mass. Readjustment resulted in a change in State Plane and Universal Transverse Mercator (UTM) coordinate systems with respect to geographic coordinates (latitude and longitude) and each other. In the 48 lower states differences range from 0 to 110 m (360 ft) and up to 200 m (660 ft) in Alaska and 400 m (1310 ft) in Hawaii. As of this writing, nautical maps are being published with the new horizontal datum, but to date USGS maps have not been regularly published with the new datum. Eventually all published charts and maps will reference the 1983 NAD. Shrink and stretch is a problem which can occur over very short time periods with paper maps. Knowler and Gorman (in press) estimate potential changes between 0.03 and 0.25 mm (0.001 and 0.01 in), which at 1:10,000 scale is $\pm 0.3 - 2.5$ m (1 - 8 ft) of ground distance. This problem can be avoided by using maps printed on a stable base material such as mylar.

12. One additional factor to consider when measuring shoreline change from maps is which shoreline has been mapped. Mean-high-water (MHW) and mean-low-water (MLW) are the two most commonly mapped shorelines. On gently sloping beaches with a moderate tidal range, the difference can be significant and corrections to a common position must be made when using maps with different shorelines. USGS topographic maps generally depict the shoreline at the MHW position, although newer maps may also have the MLW line plotted. NOS T sheets often have the MHW line marked as bold and the MLW shoreline is dashed.

Historical Maps

13. The question of accuracy becomes even more important when dealing with maps made prior to the 1941 National Map Accuracy Standards. Old maps are extremely useful for determining the long term history of shoreline change, but their accuracy must be carefully evaluated. Earliest NOS T sheets (US Coast and Geodetic Survey) date back to the 1830's and USGS topographic maps date back to formation of the USGS in 1879. Accuracy of regional maps

developed prior to these dates are highly suspect. Local maps may be accurate enough for quantitative shoreline change measurement, but regional maps can, at best, be used only for qualitative assessment of shoreline movement.

14. Originally, T sheets were made from actual topographic field surveys (modern maps are made from air photos). Shalowitz (1964) notes that during these surveys, mapping the high-water shoreline was the most important consideration. However, accuracy of early surveys can still be questioned since the only standards were those maintained by individual field party bosses. In 1840 the first superintendent of the US Coast and Geodetic Survey, Ferdinand Hassler, issued instructions to carefully survey the high-water shoreline (Everts, Battley, and Gibson 1983). While surveying the high-water line, the low-water line was to be mapped by taking offsets, unless the two lines were far apart, which would require separate surveys.

15. More specific instructions on topographic mapping of the shoreline were written in 1889 by Wainwright in the Plane Table Manual. Shalowitz (1964) interprets instructions to field parties as follows:

"The mean high-water line along a coast is the intersection of the plane of mean high water with the shore. This line, particularly along gently sloping beaches, can only be determined with precision by running spirit levels along the coast. Obviously, for charting purposes, such precise methods would not be justified, hence, the line is determined more from the physical appearance of the beach. What the topographer actually delineated are the markings left on the beach by the last preceding high water, barring the drift cast up by storm tides."

"In addition to the above, the topographer, who is an expert in his field, familiarizes himself with the tide in the area, and notes the characteristics of the beach ... and the tufts of grass or other vegetation likely along the high-water line."

16. In summary, Shalowitz (1964) notes it was the intention of the surveyors to determine the line of MHW for delineation on maps, and therefore, despite the lack of standards, this task was not treated lightly by individual survey parties.

17. Just how precisely the MHW line was located on these early surveys

was also addressed by Shalowitz (1964). He notes,

"The accuracy of the surveyed line here considered is that resulting from the methods used in locating the line at the time of survey. It is difficult to make any absolute estimates as to the accuracy of the early topographic surveys of the Bureau. In general, the officers who executed these surveys used extreme care in their work. The accuracy was of course limited by the amount of control that was available in the area."

"With the methods used, and assuming the normal control, it was possible to measure distances with an accuracy of 1 meter (Annual Report, US Coast and Geodetic Survey 192, 1880) while the position of the planetable could be determined within 2 or 3 meters of its true position. To this must be added the error due to the identification of the actual mean high water line on the ground, which may approximate 3 to 4 meters. It may, therefore, be assumed that the accuracy of location of the high-water line on the early surveys is within a maximum error of 10 meters and may possibly be much more accurate than this. This is the accuracy of the actual rodded points along the shore and does not include errors resulting from sketching between points. The latter may, in some cases, amount to as much as 10 meters, particularly where small indentations are not visible to the topographer at the planetable."

18. Measurement accuracy of the MHW shoreline on early surveys is thus dependent on a variety of factors, not the least of which was the ratio of actual rodded points to sketched data used by an individual surveyor. The more sketching used, the lower the overall accuracy. However, by means of triangulation control, a constant check was applied to the overall accuracy of the work so that no large errors were allowed to accumulate.

19. Based on this knowledge of topographic and cartographic procedures used in the past, use of old T sheets and quadrangles for quantifying shoreline change seems reasonable provided potential errors are recognized and stated. It must be remembered that rates of shoreline change derived from analysis of maps and air photos cannot be considered absolute. Neither the

accuracy of historical maps or modern maps is sufficient to give more than a good estimate of trends in shoreline erosion or accretion. Accuracy of original data sources are just not sufficient to discriminate between shorelines measured at close intervals of time or with slowly changing shorelines.

20. For example, assume a shoreline is eroding at 1 m/yr. After 8 years the shoreline would have moved landward 8 m (26 ft). If we wanted to determine the rate of retreat of that shoreline using two maps we would have to consider the error present in each map. Accuracy standards for modern NOS T sheets allows an error of up to 4.9 m (16 ft) in locating the shoreline. Summing the error for each map gives us a error band of 9.8 m (32 ft, additional sources of error could be added to this). The 8 m (26 ft) of actual erosion falls within this error band and thus the observed map differences cannot be considered significant. If we examine the same shoreline on two maps 100 years apart, 100 m (328 ft) of shoreline change is significant in comparison to 9.8 m (32 ft) of error. In another instance, if our rate of shoreline change were only 0.1 m/yr (as is the case with many bay shorelines) over 50 years we would have only 5 m (16.5 ft) of change, which again falls within the 9.8 m (32 ft) band of error.

21. In summary, to quantify historical shoreline change rates with some degree of confidence requires shoreline change to be large or the time interval between maps or air photo sets to be large. It is also useful to have intermediate data sources between the first and last dates to serve as a check on overall rate of shoreline change.

Near-Vertical Aerial Photographs

22. Generally, only very long term trends can be determined from NOS T sheets or USGS topographic maps since they are produced at infrequent intervals. This may preclude a detailed understanding of short term physical processes and morphological responses. Additionally, many details of the subaerial beach are not represented on these maps, which can make location of control points for shoreline analysis difficult and eliminates the use of some scientifically significant information. Air photos can be used to supplement shoreline change measurements by providing data on a shorter time interval and with level of detail unavailable with maps.

23. The use of air photos as a tool for measurement of shoreline change began in the late 1960's (Moffitt 1969, Langfelder, Stafford, Amein 1970, Stafford and Langfelder 1971). Prior to this, air photos had been used to qualitatively assess changes in coastal landforms. Vertical black and white air photos date back to the late 1920's, but reasonably good quality stereo air photos were not available until the late 1930's. In recent decades, air photo missions have been flown by numerous federal, state, and private organizations, making temporally frequent near-vertical aerial photography available at a reasonable cost for most US shorelines.

24. For locating coastal features in the field, good quality air photos can be used directly with less concern for accuracy. However, air photos cannot be treated as maps for quantification of shoreline change. A variety of distortions are inherent in air photos which must be eliminated or minimized to reduce measurement errors to an acceptable level. Almost all features on an air photo, except those near the center of the photo, occupy positions other than their true relative map positions. Photographic distortions due to camera optics is a problem in older air photos, but is not a big consideration for mapping cameras manufactured since the mid-1940's.

25. Relief or elevation displacement, due to large vertical changes in topography can also be a source of error. At the moment of exposure, features further from the lens, such as valleys, appear at a smaller scale on the air photo than features that are closer to the lens, such as mountains. The displacement of points on an air photo as a result of terrain relief, is radial from the nadir point (the point vertically below the camera) (Figure 1). For truly vertical aerial photographs the nadir point and principal point (center of the photo) coincide. Displacement of an image due to relief displacement (d_r) can be calculated as:

$$d_r = rh/H$$

where r is the distance on the photograph from the center to the image of the top of the object, h is the ground elevation of the object, and H is the flight altitude of the camera relative to the same datum as h (Wong, 1980). Most coastal features have low relief so that radial distortion due to elevation differences is not a serious problem. However, measurement of shorelines backed by bluffs and cliffs with vertical relief of several meters

could result in errors. The position of stable points on top of bluffs relative to shorelines at the base could be significantly displaced. For example, if a control point located on top of a cliff 10 m (32 ft) above mean sea level (MSL), is 7 cm (2.8 in) from the center of the air photo, and the altitude of the airplane was 1463 m (4800 ft) above msl (with a 152.4 mm (6 in) focal length lens, this would correspond to a 1:9600 scale air photo) its geographic position would be displaced 0.48 mm (.02 in) on the air photo, which corresponds to 4.6 m (15 ft) of displacement on the ground. Depending on the relative positions of land and sea, this could be falsely interpreted as shoreline erosion or accretion.

26. Scale variations across the photo due to tilt can result when the airplane attitude is not exactly parallel to the mean plane of the earth's surface at the instant of exposure. About half of the near-vertical aerial photographs taken for domestic mapping purposes are tilted less than 2 degrees, and few are tilted more than 3 degrees (Wong 1980). Up to 7 degrees of tilt can occur in air photos taken for non-mapping purposes. Many coastal scientists have ignored the problem of point displacement due to tilt in imagery. Some correction for tilt distortion must be made on almost every air photo prior to mapping. The relationship between a tilted and exactly vertical air photo is illustrated in Figure 1. On the upper side of the air photo, scale is larger and images appear to be displaced radially toward the isocenter, and radially away from the isocenter on the lower (smaller scale) side of the air photo.

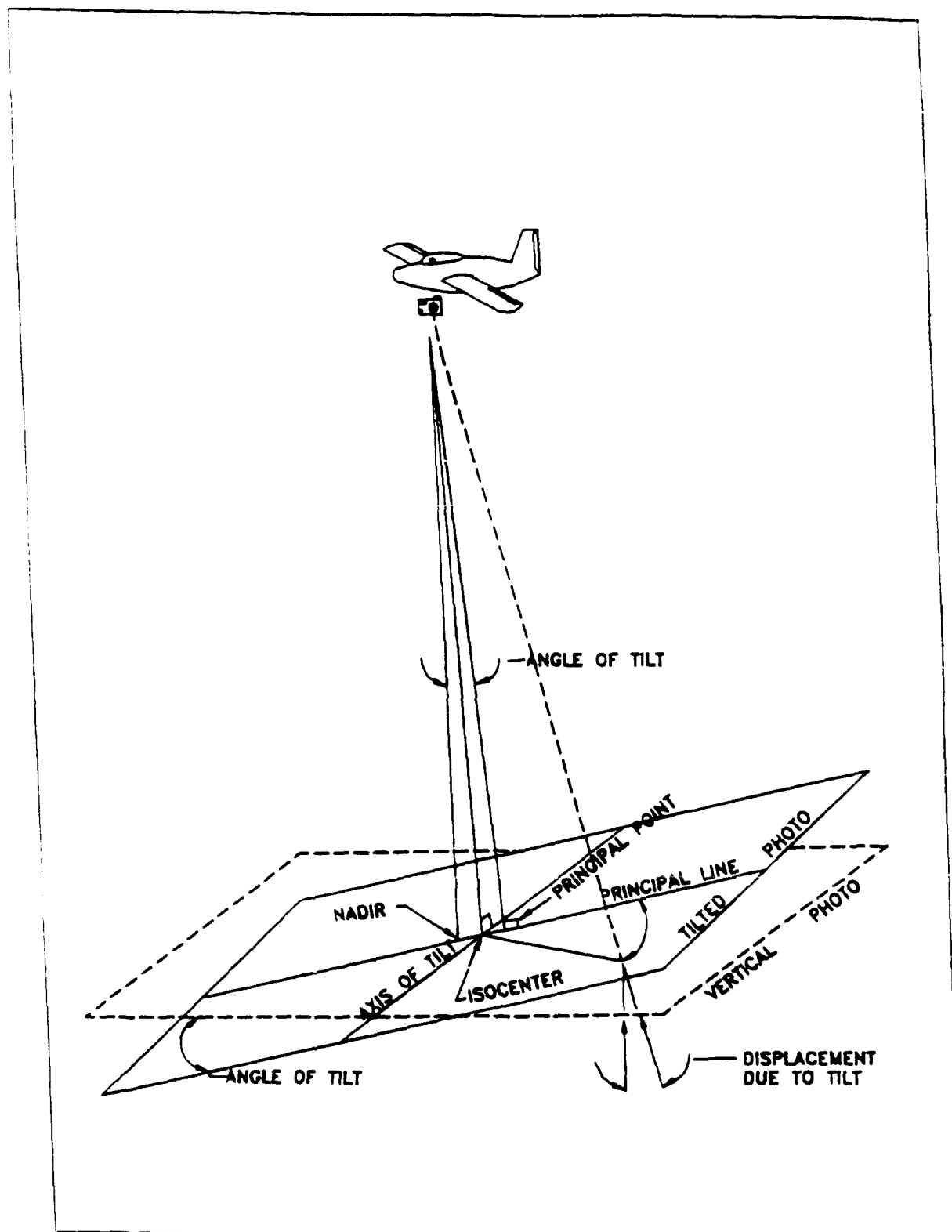


Figure 1. Shows relationship between a tilted and exactly vertical photograph.

27. Displacement of a point on a air photo due to tilt (D_t) from its actual ground position can be calculated using the following relationship (after Wolf 1983),

$$D_t = [r^2(\sin t)(\cos^2 P)]/[f - (r \sin t)(\cos P)],$$

where r is the distance from the point to the isocenter, f is the focal length of the lens, t is the angle of tilt of the photograph, and P is the angle measured clockwise from the principal line to radial line between the isocenter and the point (within the plane of the photograph). As is apparent from this equation, the amount of displacement increases with distance from the isocenter and with increasing tilt. Using air photos with minimal tilt and working only at the center of the air photo minimizes point displacement. However, for a tilt angle of only 1 degree, a point 10.0 cm (3.9 in) from the isocenter and 40 degrees from the principal line on a 1:20,000 air photo, would have an error of 6.5 m (21.3 ft) in its true ground location. An air photo with 3 degrees of tilt would yield an error of 19.7 m (64.6 ft) in its ground location, which means a shoreline could be displaced by this amount from its actual position. Clearly, unless one is working only in the center of a air photo, some correction for tilt distortion must be made.

28. One other possible source of measurement error in air photos is changing scale along the photographic flightline. Especially in light aircraft, altitude of the airplane may change slightly as it follows a flight line. The result is that scale may vary slightly from one air photo to the next. Exact scale of each air photo should be determined so that appropriate factors are used when digitizing or scaling data from a air photo. Photographic scale (S) can be calculated by,

$$S = 1/(H/f)$$

where f is the focal length of the camera lens and H is the height of the camera above the mean elevation of the terrain (in similar units) (Wong 1980). The result is a representative fraction corresponding to map scale. Scale may also be determined if the distance between two points or size of an object is known in the field or on an accompanying map.

29. To illustrate the effect of scale variation the following example is presented. At the start of an air photo mission the elevation of the plane is 3048 m (10,000 ft) and a 152.4 mm (6 in) focal length lens is used, for a scale of 1:20,000. However, if the elevation of the aircraft changes by 7.6 m (25 ft) during the mission (15 m (50 ft) is not uncommon in small light planes), at the moment of exposure, the scale of that air photo will be 1:19950. If we use this air photo and measure the distance between a stable point and a shoreline position as 7 cm (2.8 in) apart, assuming a scale of 1:20,000 we would calculate ground distance between the stable point and the shoreline to be 1400 m (4593.2 ft). However, if the scale is actually 1:19950, the distance between the points is 1396.5 m (4581.7 ft), which would effect a 3.5 m (11.5 ft) error in location of the shoreline.

Other Sources of Error

30. In addition to errors inherent in maps and air photos used for data collection, errors in shoreline positions can be introduced from interpretation and physical measurement of the shoreline and control points. On maps the shoreline is delineated; however, on air photos the shoreline must first be annotated by a trained interpreter. The high water line on a beach, generally recognized by a change from dark to light tones, is usually mapped as the shoreline (Stafford and Langfelder 1971). Correct interpretation of this line, and careful annotation are required to avoid large errors. Even width of the annotated line may introduce an error in precision of several meters at ground scale. Most techniques require location of stable control points on maps and air photos. Road intersections and buildings are logical control points, but scale of the air photo or the undeveloped character of a coastline often eliminates these features from the photo scene. In these cases, other, less precise control points can be used (e.g. a meander bend in a tidal creek which appears to have remained stable over the time span of the shoreline change study), or control must be bridged from adjacent air photos. Unless high-precision stereoscopic plotters are used for bridging, both of these alternatives reduce accuracy of the shoreline measurement.

31. Modern digitizers are accurate, however, some small amount of error can still be introduced (e.g. a standard Calcomp 9100 model digitizing tablet has a accuracy of ± 0.254 mm (0.010 in), which at a scale of 1:9600 is a

potential ground error of ± 2.4 m (7.9 ft)). However, the precision with which an operator can visualize and move the cursor along a line can lead to greater errors (Tanner 1978). Fortunately, digitizer and tracking errors are random and are dampened when averaged over finite distances of shoreline. Depending on which technique is used for making shoreline measurements, other errors may occur from physical measurements on the maps and air photos.

32. When considering all of the potential errors discussed above, it should be remembered that the discussion applied to only one map or air photo. When making temporal comparisons of shoreline position, error is cumulative since separate maps or air photos are being used, each with their own associated error. In addition, seasonal and water level differences between maps and air photos must be considered. The position of the shoreline can vary significantly from summer to winter, from high tide to low tide, and from mild conditions to storm conditions. Data sets should be consistent in season, tide, and weather conditions, to eliminate the potential for introducing large errors. For example, assume an area has a shoreline change rate of 2 m (6.5 ft) per year. If it is examined over a 5 year period 10 m (32.8 ft) of change would be expected. Assuming tidal range in the area was 1 m (3.3 ft) and beach slope was 5 degrees; if one data source depicted the shoreline at high tide and the other showed it at low tide, the shorelines would be 11.5 m (37.7 ft) apart. In this case, error due to differences in tide is greater than the measured amount of shoreline change. Using seasonally different data sets, or mixing storm data with non-storm data, has potentially greater deleterious impacts on the results.

33. In summary, a number of important factors should be considered when quantifying change in shoreline position. First, original data sources and techniques used to extract data must be high quality so that measurement of shoreline position can be as precise as possible. Map and air photo techniques developed for field use or desk top measurement are not suitable for most shoreline mapping projects. Second, large scale maps and air photos have the greatest potential for providing accurate shoreline change measurements. Map accuracy standards dictate that a 1:10,000 scale map has less error associated with it than a 1:24,000 scale map. Third, temporal frequency with which shorelines are compared must be consistent with calculated errors in the mapping procedure so that the magnitude of change is

greater than potential errors. As discussed above, larger temporal spacing between data sets improves reliability of shoreline change measurements.

Shoreline Mapping and Analysis Techniques

34. The use of maps and air photos to determine rates of shoreline change generally requires two separate tasks: compilation of a composite shoreline change map, and analysis of the composite map to determine specific rates of change along the shoreline. A variety of techniques have been presented in the literature for compiling shoreline change maps, but many of these techniques still require hand measurement of the composite map to generate data for determining rates of change. Other techniques have been developed to determine shoreline change rates directly from original data sources without developing a shoreline change map. More recently, automated systems have become available which will allow compilation of shoreline change maps and rapid calculation of shoreline change rates.

35. Production of shoreline change information using only maps and charts is a straight forward process (potential errors, such as datum changes, must be corrected). It simply involves enlarging or reducing all maps and charts to a common scale and overlaying them. Once overlaid, a composite map can be drawn and changes in shoreline position can be measured. Enlargement or reduction and overlaying can be accomplished in a variety of ways. Numerous instruments, such as a Map-o-Graph, Zoom Transfer Scope, and several types of projecting light tables can make this an easy manual task. Alternatively, map data can be digitized, and with a variety of software packages can be plotted at a common scale. Automation of the processes is a good choice if many shorelines are to be mapped. Once a composite shoreline map is completed, determination of rates of change along the coast can proceed.

36. The use of air photos, with or without maps, for determining rates of shoreline change is significantly more involved than just using maps. This is because of relief and tilt distortions inherent with air photos, as well as scale variations from aircraft height. Stafford (1971), and Stafford and Langfelder (1971), present the point measurement technique for determining shoreline change rates from air photos. This technique uses only the center

of air photos, which minimizes tilt distortion (relief distortion is not a problem for most coastal areas unless cliffs border the coastline). Scale variations must always be corrected. Stable points are selected along the coast, and from these measurements, adjustments are made to the shoreline on each air photo and map relative to a cartesian coordinate system. From these data, rates of shoreline change can be calculated in the vicinity of each control point. This technique does not produce a composite shoreline change map and is limited in density of measurements to the number of control points available.

37. Any technique which attempts to use air photos to produce an accurate composite shoreline change map must rectify the air photo or data derived from the air photo for tilt and relief distortion and scale variations. In recent years a variety of manual techniques have been used. Most photogrammetric companies and government agencies can produce rectified air photos by removing tilt and scale variations on large stereoscopic plotters. These machines essentially take the air photo and put it back into its tilted position, then project the scene downward at the proper scale. The projected image has all tilt and scale variations removed, producing a rectified vertical aerial photograph that can be treated as a regular map. Smaller instruments, such as the Vertical sketchmaster work on the same basic principle to remove tilt, but are not as precise in their operation. Projecting instruments, such as light tables and the Map-O-Graph can remove scale variations between air photos, but cannot correct for tilt distortion. The Zoom Transfer Scope likewise can correct for scale variations, and partially correct for tilt. It can shrink or stretch an image in one direction, however, since tilt causes half the air photo to have a larger scale and half to have a smaller scale, shrinking or stretching in one direction is not sufficient to remove all tilt. Aligning carefully selected control points, and working in small areas of the air photo at a time has produced best results (Anders and Leatherman, 1982).

38. Over the past decade, a variety of automated techniques have been developed for producing composite shoreline maps from air photos. Several personal computer software packages are available which allow a small mapping laboratory to produce composite shoreline maps from original map and air photo data sources. In addition, a few coastal scientists have developed their own

automated techniques (Leatherman 1983). For air photos, most of these techniques use a least squares adjustment to rectify the data to a non-tilted condition. This procedure involves digitizing control point information on a air photo and comparing the location of each point to its known location in a geographical coordinate system. The least squares procedure then develops a correction factor to adjust control points to their "proper" position. In so doing, the correction is not specific to tilt or scale variation, but simply corrects for all inherent errors simultaneously. The resulting correction is a "best fit" position for all control points. Using more control points generally improves the fit by distributing the error between more points. Once a correction factor is calculated, it is applied to all shoreline data points digitized from the air photo. Corrected data can then be added to a composite shoreline map. This same general technique is employed in the CFMS discussed below.

39. After development of a composite shoreline change map, data must be extracted to determine rates of shoreline change along the coast. Recent studies by Byrnes et al. (1989) and Anders. Reed, Meisburger (1990) have determined shoreline change rates at 50 meter intervals along the coast, but if needed, smaller intervals could be used. Values for each interval can be summarized to determine shoreline change rates for any length of coast. Data collection for determination of change rates can either be accomplished manually or using an automated technique. The manual process involves establishing transects perpendicular to the composite coastline at the desired along-the-coast interval and measuring distances between shorelines along each transect. The amount of change is divided by the time interval between shorelines to determine rate of change. This should be accompanied by temporal standard deviation of the change rate for each transect. Spatial standard deviation is required if shoreline change data is summarized for an area. The manual technique is suitable if the along-the-coast interval is large so that a limited number of data points are collected.

40. For projects covering large areas with a high density of shoreline change measurements, automated techniques can save significant amounts of time and money. The basic procedure is similar to the manual technique. Transects are established perpendicular to an arbitrary baseline that is parallel to the composite shoreline, and the intersection of these transects with each

shoreline represents a data point. Baseline length was based on general shoreline orientation and natural breaks in shoreline continuity. Anders, Reed, and Meisburger (1990) used a cartesian coordinate system for each baseline with the x-axis directed alongshore and the y-axis directed offshore. The digitizer x-increment matched the composite map scale to generate shoreline change data at approximately a 50 m (165 ft) along-the-coast interval. Byrnes et al. (1989) used a similar technique, however, high-water shoreline positions were digitized with reference to a geographical graticule. Digital data were converted to state plane coordinates and referenced to a common baseline parallel to the shoreline trend. Cubic spline interpolation was used to compare temporal data at common alongshore positions.

41. An improvement to this technique is currently being developed (Knowles and Gorman, in press). In an iterative process for each shoreline, the system, known as COAST (COmputer Analysis of Shoreline Trends) creates a best fit line through a series of digitized shoreline points (the number of points is user specified) using a linear regression. These small straight line segments for each shoreline are averaged to create a mean shoreline position. COAST establishes transects perpendicular to the mean shoreline at an along-the-coast interval specified by the user, and searches the digitized data to determine the intersection of each transect with each shoreline. Data along each transect are then used to calculate a rate of shoreline change.

42. Shoreline change information should include average shoreline change rate, standard deviation (temporal and/or spatial) of that rate, and also the maximum envelope of change. Average shoreline change can be tabulated for various temporal intervals depending on original data sources. It should be noted that average rate is really net average rate of change, and that no inference is made as to how a shoreline responded between the two dates. The entire change may have occurred as the result of one or two major events; this procedure simply distributes change equally over the time increment between dates. Standard deviation is a measure of either the temporal or spatial variability of the average change rate. Where standard deviations are high, shorelines are quite variable and the usefulness of an average rate for predicting future shoreline position is reduced. Maximum envelope of change identifies the entire range of shoreline excursion for the data available. It is possible that at some point during the total time

interval used to calculate average change, the shoreline may have shifted outside of the locations portrayed on the first and last date.

43. In the technique discussed above, problems routinely occur which require special treatment. Most of these problems, such as control point selection in areas where the coastline has little human development, have been reviewed. One problem not discussed is what to do in areas that show pronounced shoreline reorientation and extremely rapid changes in the alongshore direction, as might occur in the vicinity of inlets, spit tips, and at capes. The validity of using a transect method to measure changes in these dynamic areas is marginal since no transect can be created which is perpendicular to all composite shorelines. An area measurement technique, such as that applied by Everts, Battley, and Gibson (1983), could be used to quantify areal changes in these locations. Manual measurements by a qualified interpreter can also provide useful information for quantifying changes in these dynamic regions.

PART III: AN EVALUATION OF CFMS

44. A 1981 (photorevised 1988) USGS 1:24,000 topographic map and 11 near-vertical aerial photographs (taken 8/17/88) were used to evaluate CFMS. CFMS was used to rectify all aerial imagery to stable ground control points along an area extending from St. Marys entrance channel southward for approximately 8.9 km (5.5 miles) (Figure 2). This site, photography, and base map were selected because an abundance of ground control points were available. This methodology allowed various test scenarios to be constructed for evaluating CFMS's ability to accurately calculate position coordinates (X and Y) under variable ground control point conditions and ultimately plot composite shoreline maps for evaluation of shoreline change rates. A series of tests also included a unique "bridging" photo technique for areas with little or no ground control points.

45. The typical procedure for using CFMS to plot composite shoreline maps requires selection of control points that can be located on all maps and air photos. The ground position of these control points must be known in some cartesian coordinate system from field surveys or precise locating on an accurate base map. In this study, a base map was used to determine the control point coordinates. These same points are then digitized on the air photos. CFMS then uses a least squares transformation rectifying the control points on the photo to the known positions. A Calcomp 9000 digitizer was used in determining positions of various ground control points (from USGS 1:24,000 T-sheet) along Amelia Island's northern shoreline. Control points were carefully selected to minimize terrain relief effects. Point locations included street intersections along with a few small (low elevation) private homes. These control point X, Y coordinates (from Calcomp 9000) were used to create a permanent ground control point file that formed the standard for all subsequent work with CFMS. The procedure adopted for quantifying this comparison is subject to limitations of accuracy and precision inherent in maps and near-vertical aerial photographs. The national map accuracy standard for a 1:24,000 scale USGS map is ± 12 m (40 ft) (Ellis 1978). In order to account for operator error (i.e. positioning the digitizer cursor in the exact position each time), and Calcomp 9000 digitizer accuracy,

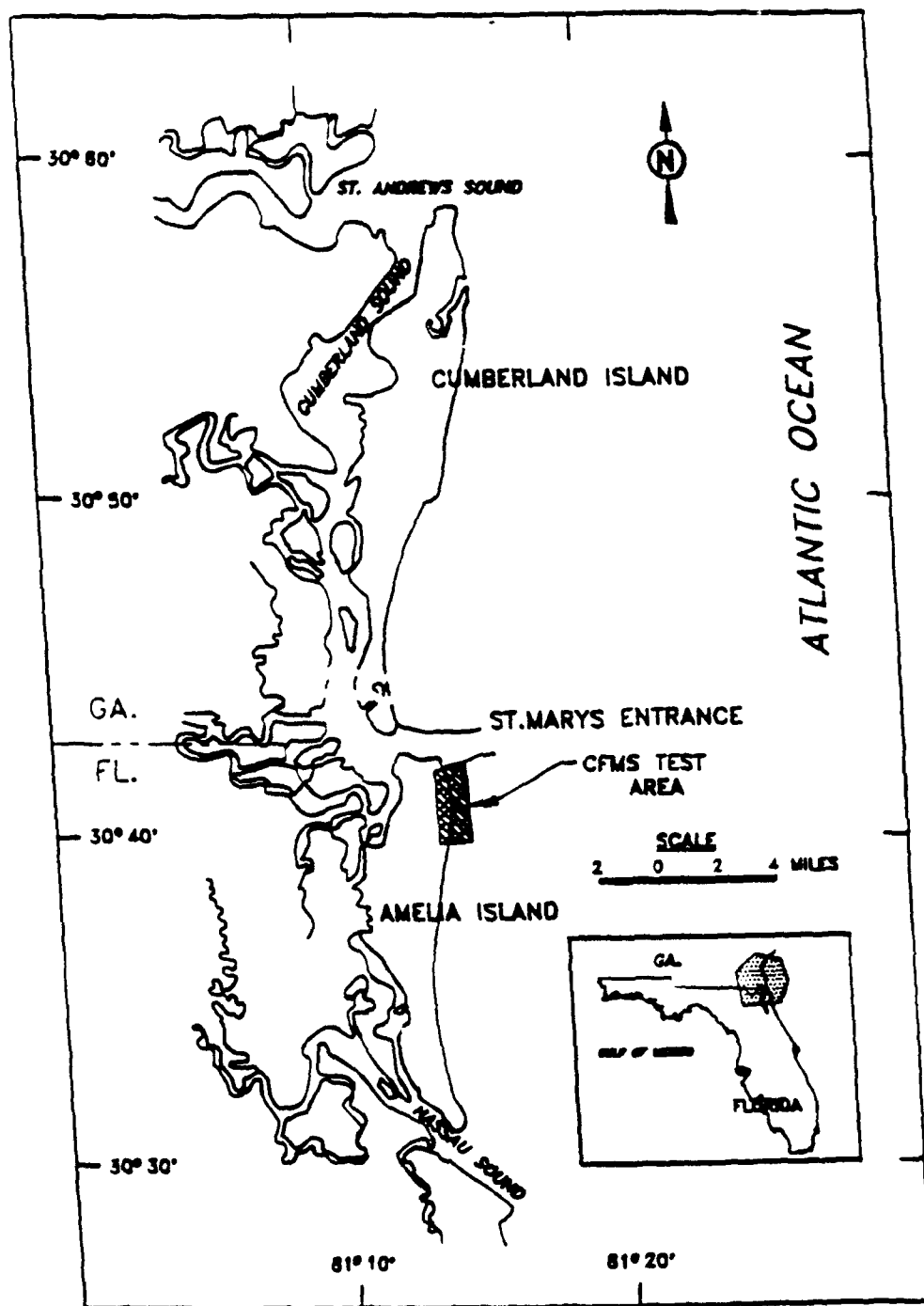


Figure 2. Location of Amelia Island and CFMS test area.

each ground control point position was digitized 4 separate times from the 1981 USGS topographic map. Differences in X coordinate positioning ranged from 0-7 m (0-24 ft), with an overall X coordinate average of 3.2 m (10.6 ft). Differences in Y coordinate positioning ranged from .61-5.2 m (2-17 ft), with an overall Y coordinate average of 2.4 m (7.9 ft). This difference in X, Y coordinates correlates to an average position difference of approximately 4.27 m (14 ft). Therefore, when digitizing ground control points, each control point should be reoccupied a minimum of 3-4 times. It is suggested that this procedure be followed when using CFMS to gage the magnitude of error associated with digitizing.

Ground Control Point Distribution

46. The importance of ground control point quantity and distribution on CFMS's ability to calculate coordinate positions was tested. Ten different test sample stations were located at various positions on a single aerial photograph (Figure 3). Stations 1-6 and 8 were located along the edges, station 7 was centered, and stations 9 and 10 were placed away from the shoreline. Each of the 10 test stations were digitized first with 9 control points, then with 4 control points (all well distributed). This test scenario was to evaluate: (1) the effect of variable number of ground control points (9 vs 4) on CFMS accuracy in determining position coordinates of these 10 test stations. (2) the effect of ground control distribution (well distributed vs poorly distributed) on CFMS accuracy in determining position coordinates of the 10 test stations.

47. Figure 4 shows differences in CFMS determined X, Y position coordinates, for 10 test stations with 9 versus 4 ground control points. The position difference values for the 10 test stations (excluding station 8) with 4 GCP's vs 9 GCP's ranged from approximately 2 m (7 ft) to 7 m (23 ft) and 1.5 m (5 ft) to 6.7 m (22 ft) respectively. Station 8's position difference was not included due to it exceptionally large difference which exceeded 213 m (700 ft). This large value reflects its distance from all other ground control points and its location on the edge of the photograph. Averaged position differences for 4 GCP's for stations 1-6 was 4.1 m (13.45 ft),

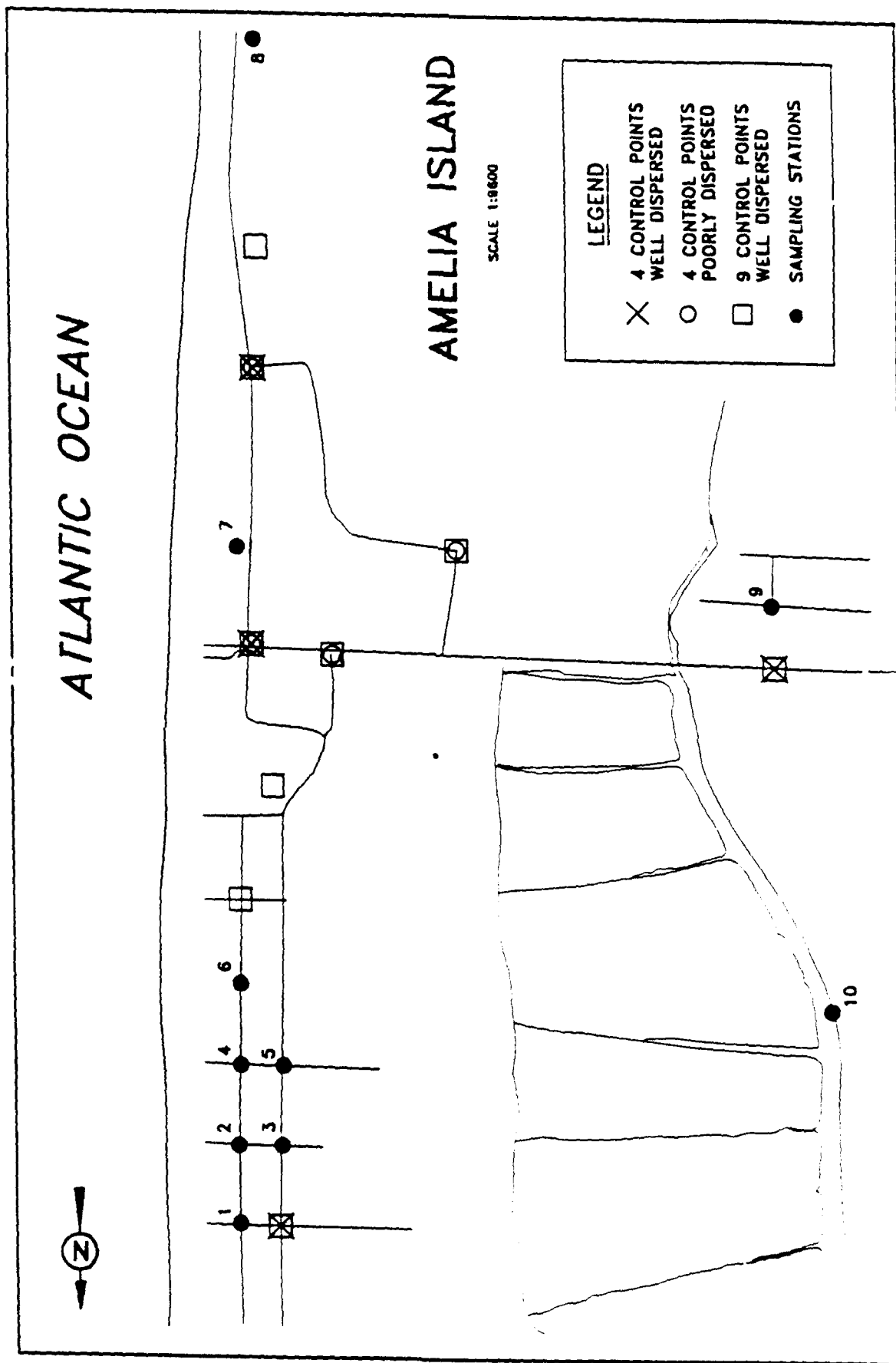


Figure 3. Test station diagram for variable number G.I.'s and variable GCP distribution

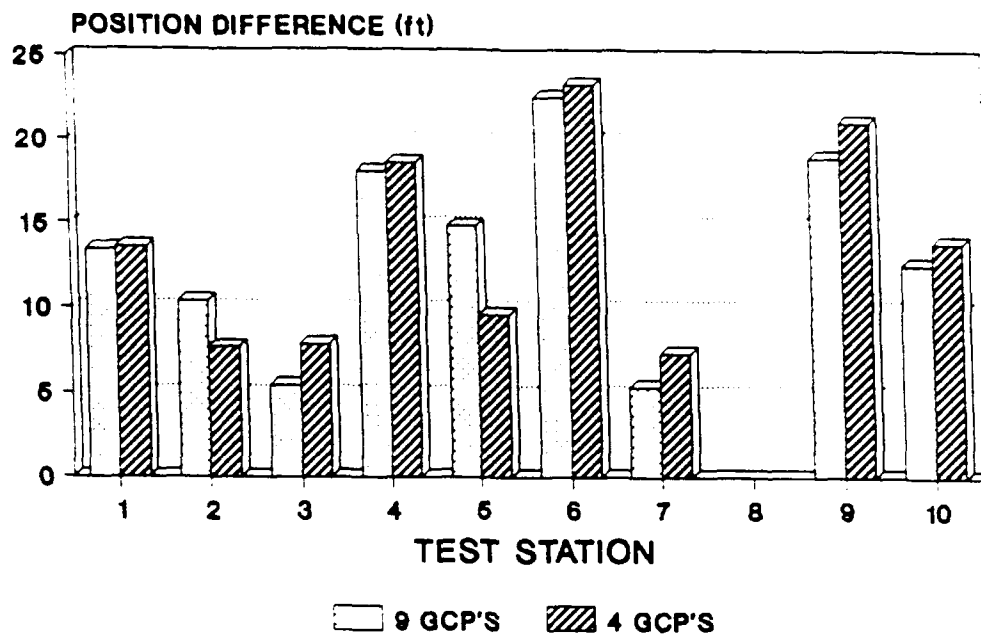


Figure 4. Position difference values for 10 test stations with Large no. GCP's (9) vs Small no. GCP's (4)

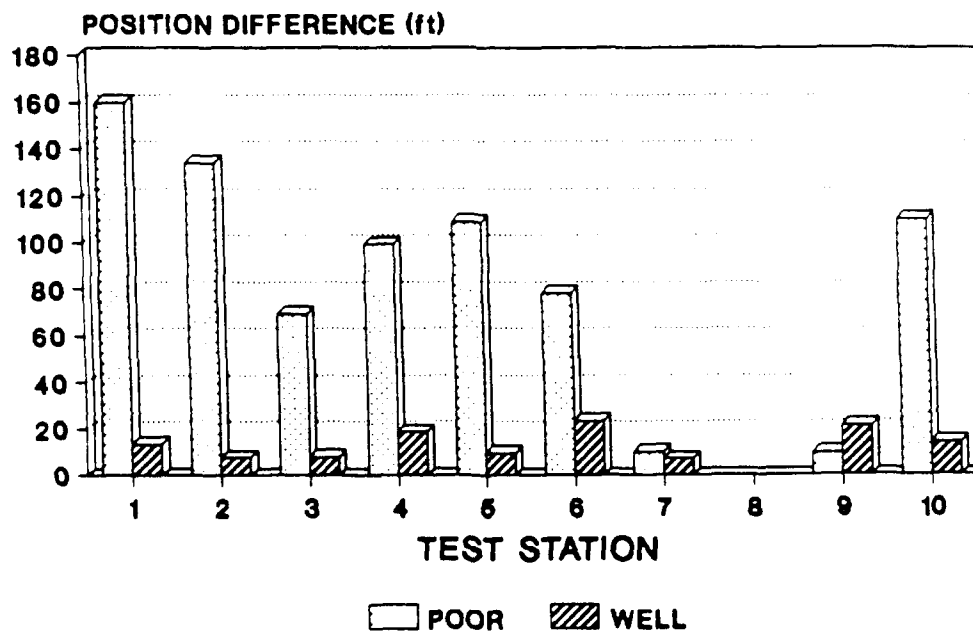


Figure 5. Position difference values for 10 test stations with Well dispersed GCP's vs Poorly dispersed

station 7 was 2 m (7 ft), and station's 9 and 10 was 4.05 m (13.35 ft). Averaged position differences for 9 GCP's for stations 1-6 was 4.3 m (14.12 ft), station 7 was 1.5 m (5 ft), and station's 9 and 10 was 4.87 m (16 ft). This graph shows that ground control point quantity is not significantly affecting X and Y coordinate positioning. However, a large number of ground coordinate points provide user flexibility for deleting certain control points. Possible blunders can be identified and corrected interactively in CFMS. Since CFMS software requires a minimum of 4 control points to develop an accurate rectification, user flexibility is lost if only 4 control points are used.

48. Under ideal conditions, GCP's should be distributed with 4 points in each corner and 1 point in the center of the photograph. This configuration permits all mapped features to fall within the controlled area of the photograph. Unfortunately, shoreline photography is typically centered over the land/water interface making it impossible to locate GCP's in at least two of the corners. Consequently, a test was performed to assess the importance of GCP distribution on the accuracy of CFMS coordinate positioning (Figure 5). The accuracy of coordinate positioning for well-distributed versus poorly distributed GCP's was ± 4 m (13 ft) and ± 55 m (181 ft), respectively. In the poorly distributed case, the errors associated with stations 1-6 tend to decrease closer to the cluster of GCP's (see Figure 3). Station's 7 and 9, on the other hand, which both lie within the GCP cluster, exhibits a relatively small amount of error ± 2.74 m (9 ft) and ± 2.13 m (7 ft) respectively. In general, these results indicate that the distribution of ground control points has a much greater affect on the CFMS coordinate accuracy than the number of GCP's. Therefore, mapping should be confined to the area of the photograph that can be rectified by surrounding GCP's.

49. Next, CFMS ability to calculate ground coordinates, of 9 designated test stations, across a strip of 7 near-vertical 1:9600 scale aerial photographs was tested (Figure 6). These 9 test stations were to simulate a typical shoreline (which is a series of X,Y coordinates) and CFMS ability to accurately calculate position coordinates, along with selection of ground control points for each photograph. This allowed the authors to; (1) test differences of CFMS calculated X, Y coordinates for the test stations vs

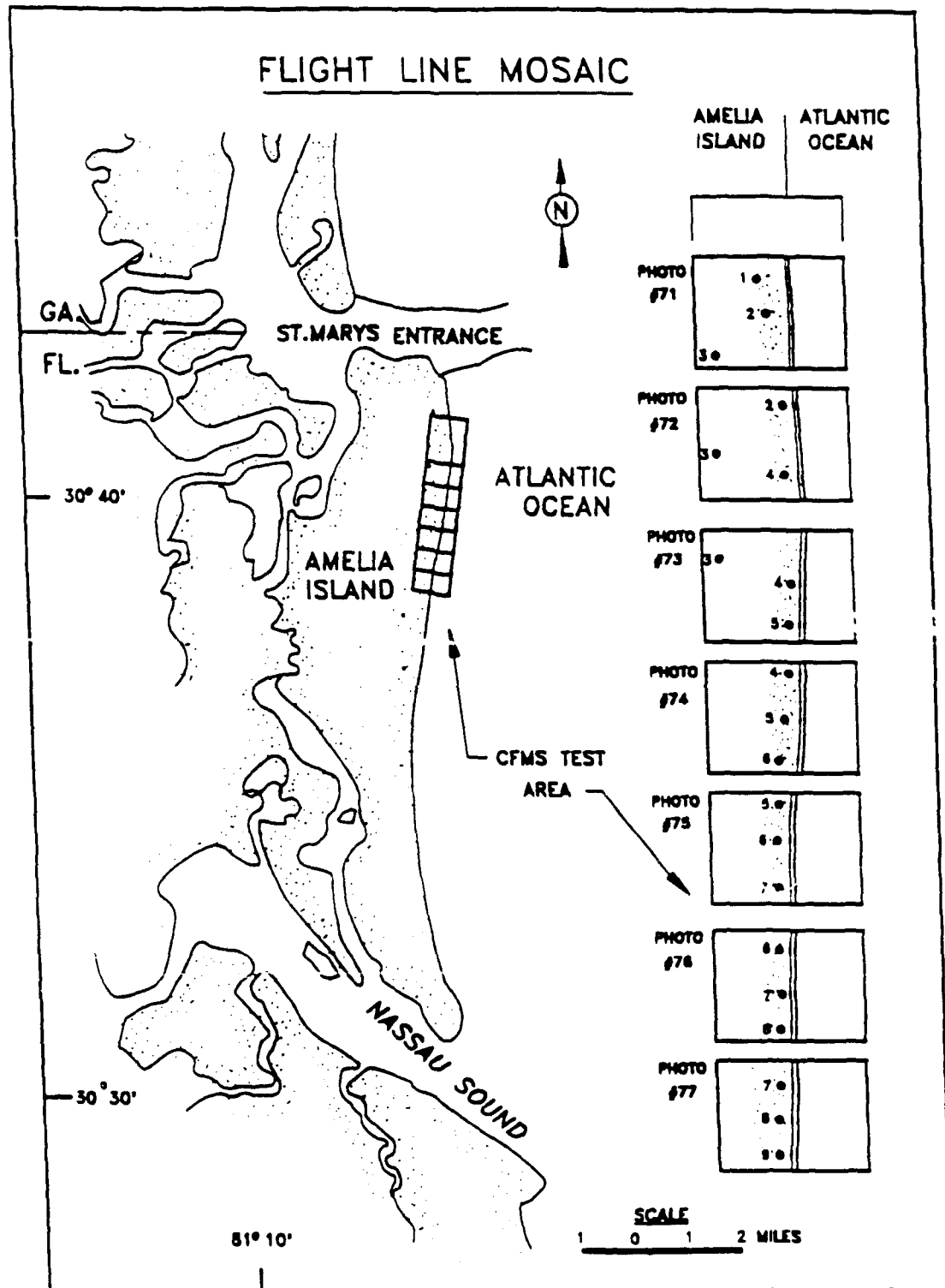


Figure 6. Flight line mosaic showing location of photographs 71-77 and test stations 1-9.

digitized base map calculated X, Y coordinates for the test stations (2) track coordinate accuracy of these test stations (simulated shorelines) as they progressed (changed position relative to the photo borders) across the photographs. A total of 17 ground control points (GCP) and 9 test stations were digitized from the 1981 USGS topographic map of Amelia Island. Test stations were a combination of road intersections (stations 1, 2, 3, 7, 8, 9) and private homes (stations 4, 5, 6). The strip of 7 near-vertical aerial photographs, labeled 71-77, (containing these 17 GCP's and 9 test stations) encompassed approximately 5.6 km (3.5 miles) of North Amelia Island shoreline. Three test stations (numbered 1-9) and a variable number of well distributed ground control points per photograph were digitized with CFMS. After photorectification of the ground control points by CFMS, each test station was digitized, and its CFMS X, Y position recorded. These CFMS coordinate positions were then compared to original base map coordinate positions. Each photograph test procedure was repeated 4 times for all 9 test stations. Averaged coordinate position differences between the base map and CFMS coordinates are shown in Figure 7. In Figure 7, test stations 1 and 9 were excluded from the test results because they are found only once on the first (71) and last photograph (77) of the photo strip, respectively. Therefore, only test results for stations 2-8 were used. The range in position error (CFMS vs Calcomp 9000) varies from approximately 6 m (19 ft) to 23 m (75 ft) with a mean error of 12 m (40 ft). Only test station 7 (middle photograph value) showed an exceptionally large averaged position difference. This large difference was probably due to a bad control point. Based on the data from figure 7, it appears the center test station (located closest to the photocenter) displayed greater accuracy than the adjacent test stations. The middle photograph position differences ranged from 6m (19 ft) to 9.4 m (31 ft) which is well within the predefined error threshold. It's a well known fact, that points measured near the center of photos will have increased accuracy (due to a reduction of tilt displacement), this data supports that conclusion even after CFMS rectification. Furthermore, it suggests that CFMS does not remove all errors inherent in the photographs and therefore selecting shoreline data near the photo center (and having 60% overlap in the photo to allow this) is still an important consideration.

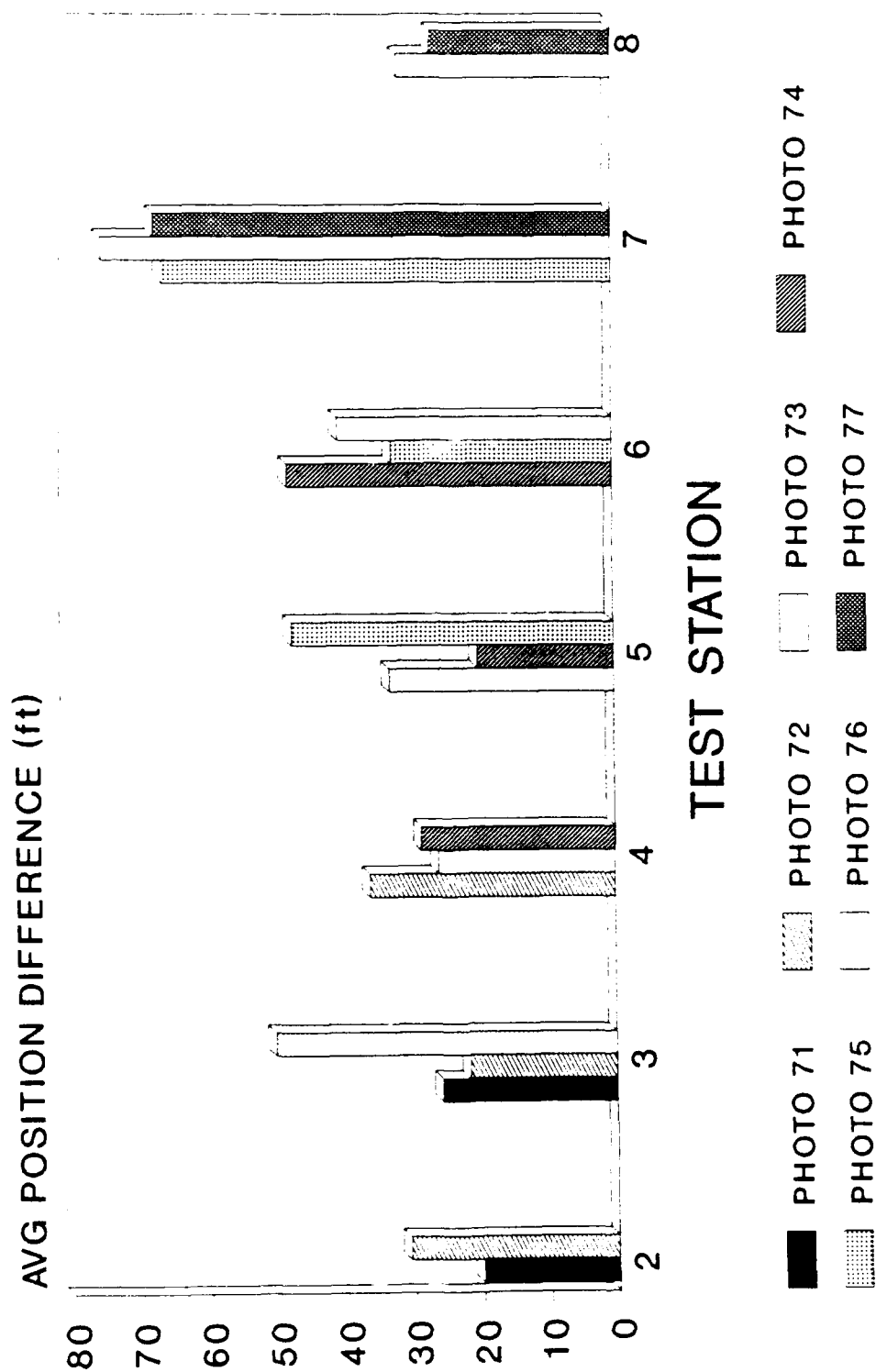


Figure 7. 7 photograph GCP test showing average position differences when comparing CFMS location to base map location.

THE BRIDGING CONCEPT

50. Pristine areas of coastal shorelines often lack sufficient ground control points, and large scale photos have limited ground control coverage, prohibiting accurate digitization of the shoreline. Selection of improper control points will adversely affect the accuracy of shoreline measurements. Objects selected for reference points (ground control points) have to have stable locations that do not move with time from natural or man-made causes. Selection of these reference points can be accomplished by the naked eye, or by stereoscopic equipment, when necessary. An example of good ground control points are intersecting centerlines of paved street road intersections, sidewalks and/or the corners of buildings at ground level.

51. Bridging allows a maximum of three photographs, with insufficient ground control, to be "passed" over without sacrificing accuracy needed to compute the shoreline position. Those areas lacking sufficient ground control are assigned "pass" points, providing continuous continuity to the photo strip. A pass point is any non ground control point (tree, rocks, etc.) which can be found from one photograph to the next photograph (passed). This bridging process is superseded by a procedure called Collect. Collect permits the measurement of photo coordinates of control and pass points from air photos in a strip. Ground control and pass points are first assigned sequential identification numbers. All points and photos must be numbered correctly and consistently, and all photo measurements must be as accurate as possible. Errors introduced in this step, will be passed on to subsequent steps (i.e. Bridge). These ground coordinates are then used in Bridge to extend or densify the ground coordinate network. The CFMS users manual¹ gives the following explanation of bridging: "Bridge connects the photo coordinates to form a strip and then computes ground coordinates for each measured pass point. Bridge performs a least squares transformation to create a set of common coordinates for the entire strip. Finally, individual GCP files are created which contain the coordinates of all points found on a given photo. These files can then used to produce map overlays from the photos. Bridge

¹ Center for Remote Sensing and Mapping Science, Department of Geography, University of Georgia, 1989, COASTAL FEATURES MAPPING SYSTEM, Athens Georgia.

does not perform a full aerotriangulation solution based on X, Y and Z terrain coordinates. Consequently, the program does not account for terrain relief or correct for earth curvature effects". For this reason, accuracy of the solution is most reliable when strips are limited in size to 5 photographs and terrain relief is minimal. Two of the five photographs (one on each end) must have stable GCP's. The bridging across the three remaining photographs is performed with a combination of pass and ground control points.

Bridging (Ground control points on both ends)

52. As suggested above, a maximum of 3 photographs can be bridged. This bridging process for 3 photographs, actually involves 5 photographs. The first and fifth photographs contain ground control points (at least, 4 each), tied together by the 3 middle photographs being bridged. A mosaic of 5 photographs were assembled to test CFMS's ability to calculate X, Y coordinates for 5 test stations (2-6) on the bridged photos. Figure 8 bridges 5 photographs. Figure 9 bridges 4 photographs, and Figure 10 bridges 3 photographs. In general, results from these three bridging tests are consistently within +/- 12m (40 ft) (accuracy of original base map), with directional errors similar to results found in Figure 8 (GCP's on all photographs). This suggests, that position coordinate accuracy is not lost by the bridging process.

Bridging (Ground control points on one end)

53. The CFMS bridging program was designed for situations where control points could be located at each end of the photo strip. Control points on one end only, cause coordinate position errors to increase rapidly with distance from ground control points. As an experiment, a strip of 7 photographs were bridged (in one direction) with 7 control points starting on the first photograph. As you move away from the first photo, the number of GCP's become smaller eventually terminating, leaving only pass points to calculate X, Y positions of test stations. The results are shown in Figures 11 and 12. Position differences from test stations 2, 3, 4 range from 6 m (19 ft) to 27 m

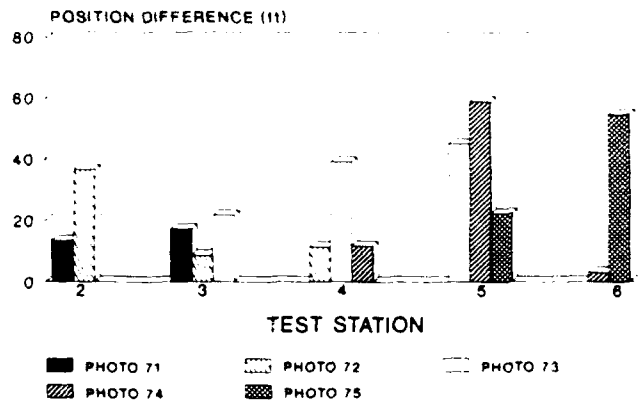


Figure 8. Position differences-Bridging 5 photographs

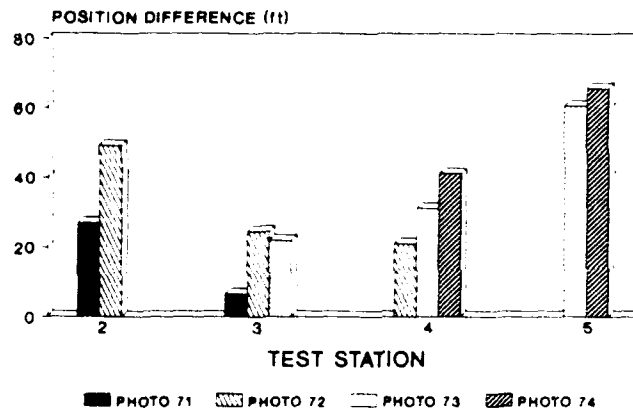


Figure 9. Position differences-Bridging 4 photographs

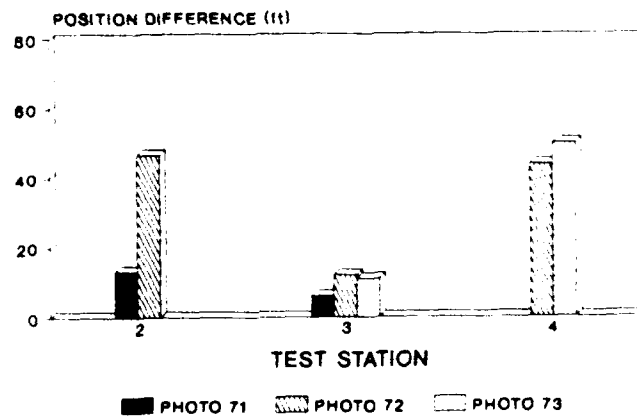


Figure 10. Position differences-Bridging 3 photographs

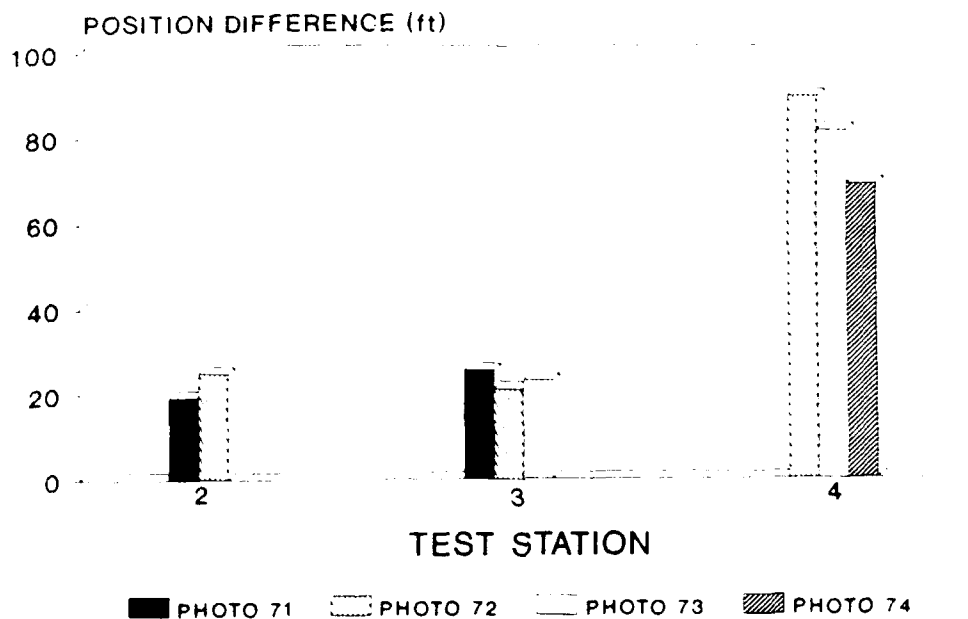


Figure 11. Position differences for test stations 2, 3, 4
- GCP's one end only.

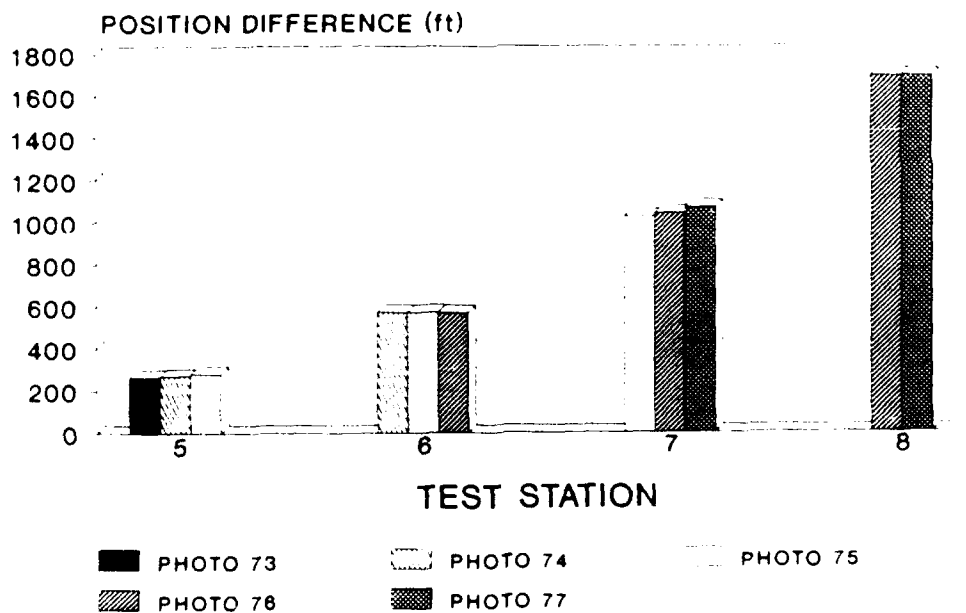


Figure 12. Position differences for test stations 5, 6, 7, 8
- GCP's one end only.

(90 ft) and test stations 5, 6, 7, 8 range from 61 m (200 ft) to approximately 503 m (1650 ft) respectively. Clearly, one ended bridging should be limited to 2-3 photos beyond the original ground control point photograph and should be performed only when no other option exists.

PART V: SUMMARY AND CONCLUSIONS

54. In any mapping task, the accuracy of the final map product and its usefulness for quantitative analysis are determined in large part by the quality of ground control points (GCP's) employed during compilation. Since many coastal areas are subject to frequent change, it is often difficult to fulfill the optimum requirements for ground control when mapping from aerial photographs. For this reason, a series of tests was devised to evaluate the accuracy of the Coastal Feature Mapping System (CFMS) for typical shoreline mapping applications encountered by the Corps of Engineers. Major variables tested included the number of ground control points employed in the solution and their distribution. Ground control points digitized from 1:24,000 scale USGS topographic maps were used in various combinations to orient 1:9600 scale aerial photographs for coordinate retrieval. It was found that the accuracy of X, Y coordinates determined from the photos is governed by the distribution and accuracy of GCP's. Maximum accuracy is obtained when all measured points are within the area bounded by the GCP's. Although at least four GCP's are required for the solution, additional points allow possible mistakes to be identified and corrected interactively. In all tests, the errors were consistent with those associated with 1:24,000 scale base map as defined by National Map Accuracy Standards. Measurements of shoreline points contained in a strip of several photographs indicated that directional errors were smaller for points located near the center of each photograph. This suggests that positions of shorelines and other features digitized in the central portions of the photographs are likely to be more accurate than those measured on the margins. The unique capability of the CFMS to "bridge" measurements across areas with little or no ground control was also evaluated. The tests demonstrated that positional accuracy of digitized points could be maintained over as many as three photographs as long as the photos on both ends of the strip were well-controlled. Bridging beyond the control is not recommended. The CFMS solution relies entirely upon the accuracy of the GCP's employed, the photo scale and photo coordinate measurement error. With this in mind, several basic principles must be recognized during a mapping operation: (1) the accuracy of base map GCP location is a major factor controlling accuracy of the CFMS solution, (2) minimum of four well-defined GCP's located in the

corners or margins of the photo are required to orient the photograph, and (3) each GCP location should be digitized several times and the coordinates averaged so as to minimize inaccuracies and errors in measurement. The users guide (Welch, 1990) contained adequate information about overall program operation, but lacked sufficient guidance for first time users. It assumes the operator is knowledgeable about basic photogrammetric and aerial photo mapping procedures. For more information on CFMS contact the Coastal Geology Unit, Coastal Structures and Evaluation Branch, Engineering Development Division, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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APPENDIX A: Shoreline Change Along a Developed Coast:
North Amelia Island, Florida

The Study Area

55. In order to evaluate CFMS, a section of shoreline along the northern end of Amelia Island, Florida was digitized and mapped. Aerial photography obtained in 1988 was the primary data source used in this evaluation. The shoreline mapped from this photography was compared with historical shorelines developed from maps and other near vertical photo sets. The base map used in this application was the 1981 (photorevised 1988) US Geological Survey 1:24,000 topographic map (Fernandina Quadrangle). The site, photography, and base map represent typical information available for Corps of Engineers shoreline change mapping applications.

56. St. Marys Entrance is a tidal inlet separating Cumberland Island, Georgia and Amelia Island, Florida (Figure 2). The inlet is about 48 km (30 miles) north northeast of Jacksonville Florida, and 48 km (30 miles) south of Brunswick, Georgia. A federally maintained entrance channel, accessing the Intracoastal Waterway, ports at Fernandina, Florida and St. Marys, Georgia, and the U.S. Naval Submarine Base at Kings Bay. Historically the main ebb tidal channel for St. Mary's Inlet hugged the shore of Amelia Island. By the 1870's the channel bifurcated around a sand bar deposited across the inlet. This bar was located 3.2 km (2 miles) offshore at about the 2.4 m (8 ft) depth contour. Inlet stabilization began with construction of the north jetty in 1881. Major changes in inlet configuration had occurred by 1905 when the jetties were complete. One main channel was confined between the jetties and the northern channel was cutoff by the north jetty. Kings Bay Naval Submarine Support Base continuously grew since the 1950's and by 1980 the channel depth was increased to -12 m (-40 ft) low water (MLW). In order for larger Trident-class submarines to use the Kings Bay facilities, project channel dimensions had to be modified. By the mid-1980's, channel dimensions were increased to a depth of -15 m (-49 ft) MLW, a width of 150 m (500 ft), and a channel length of 15087 m (49,500 ft). As a result, 1.68 million cu m (2.2 million cu yds) of sand, was placed along 5.8 km (3.6 miles) of north Amelia Island beach (Knowles and Gorman, in press).

57. The project area is part of the southeast Atlantic Coastal Plain

that consists of reworked sediments offshore and fluvial sediments from in-situ rivers. The barrier islands along the outer coast are considered drumstick barriers that are characterized by Pleistocene-age beach ridge complexes adjacent to relict lagoons and coastal marshes. Dominant wind direction is from the north and northeast, resulting in a net southerly littoral drift direction. Mean tidal range is approximately 1.8 m (6.0 ft).

58. Amelia Island is the northernmost barrier island in Florida and is part of a 320 km (200 mile) long chain of linear barrier islands. The island is approximately 21 km (13 miles) long and 3.2 km (2 miles) wide, and average elevation is less than 7.6 m (25 ft) above mean sea level. Typical geomorphic features include a gentle sloping beach backed by a series of irregular dunes 9.1 m (30 ft) to 12 m (40 ft) high, landward of a low ridge adjacent to a sandy plain extending landward for approximately 610 m (2,000 ft), and marsh deposits on the back side of the island. The beach sands generally consist of medium quartz sands with a mean grain size of 0.28 mm (1.85 phi) and a standard deviation of .48 mm (1.05 phi) (U.S. Army Corps of Engineers 1984). Typically, sand size becomes coarser to the south.

SHORELINE CHANGE ALONG A DEVELOPED COAST

59. Knowles and Gorman (in press), quantified shoreline movement for northern Amelia Island from 1857-1974. Data used for shoreline analysis consisted of NOS Topographic and Hydrographic survey sheets, and USGS Topographic quadrangle maps. Five historic shoreline surveys were used: 1857/1870, 1924, 1933, 1958 and 1974. The 1857 survey covered the St. Marys entrance area and was combined with the 1870 survey, providing complete coverage of Amelia Island's southern shoreline. In general, average shoreline position change along all of Amelia Island was .3 m (1.0 ft) of accretion per year from 1857/1870 to 1974. The area adjacent to the inlet south for 8.8 km (5.5 miles) averaged approximately 1.2 m/yr (4.0 ft) of accretion. This 1857/1870 to 1973/1974 shoreline change data provided a comprehensive data base for subsequent shoreline updating by CFMS.

60. A series of 11 near-vertical aerial photographs (taken 8/17/88) were digitized with a Calcomp 9100 digitizer, linked into a Zenith PC (MS/DOS 286, microprocesor) using CFMS software. All eleven aerial photographs were digitized along an interpreted MHW (mean high water) line based on changes in

color as described by Langfelder and Stafford 1971. Standard aerial photography provides approximately 60 percent overlap from one photograph to the next. If the entire shoreline on each photo is digitized, this shoreline overlap must be edited out after digitization is complete. This editing procedure, produces a single continuous set of X, Y coordinates representing the 1988 shoreline position. All shoreline data was then entered into COAST (discussed earlier). Shoreline position change statistics were calculated along transects spaced 300 feet along the "average shoreline". Figure 13 shows a 1988 CFMS digitized shoreline, along with COAST generated shoreline statistics. Segmented shoreline data for 1857/1870 were appended together to represent one continuous coastline for this time period. The mean shoreline movement, from St. Marys Inlet south (8 km, 5.5 miles) from 1974-1988 was approximately 1.43 m (4.7 feet) accretion per year. This accretion may represent landward movement of ebb-tidal shoals after jetty construction, and/or subsequent sand placement of beach material during St. Marys entrance channel deepening for the larger Trident-class submarines. Standard deviation reflects variability about the average mean change rate. Along northern Amelia Island, adjacent to the jetties, standard deviation values are large. Where standard deviations are high, shorelines tend to be variable, thus usefulness of average rate for predicting future shoreline position is reduced. Because of the variable accuracy, results from shoreline position change analysis are more suited for characterizing general trends and relative comparison of coastal reaches. Quantitative use of the analysis results should be used with caution.

AMELIA ISLAND STUDY

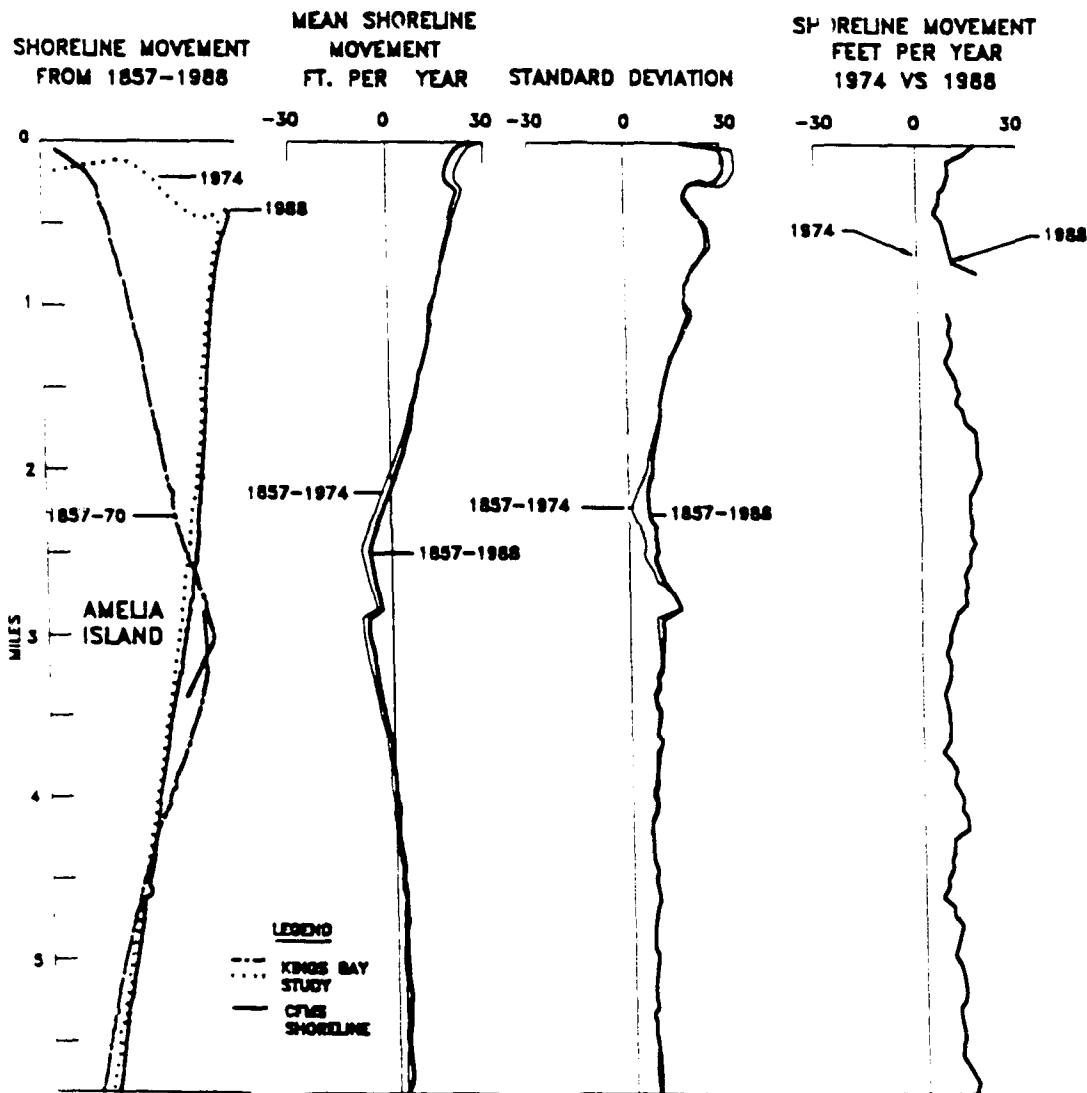


Figure 13. Updated 1988 Amelia Island shoreline, Mean Shoreline Movement, Standard Deviation, and Absolute Shoreline Movement.